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# Are aerobic interval training and continuous training isocaloric in coronary artery disease patients?

**Nele Pattyn[1], Véronique A Cornelissen[1], Roselien Buys[1], Ann-Sofie Lagae[1], Jessica Leliaert[1] and Luc Vanhees[1,2]**

## Abstract

**Background:** Aerobic interval training (IT) seems to be superior to continuous training (CT) in improving exercise capacity (peak oxygen uptake ($VO_2$)) in coronary artery disease (CAD) patients in some, but not in all studies. Based on theoretical calculations, these comparative studies stated that the energy expenditure (EE) of both programmes is similar. To date, the caloricity of both programmes has never been objectively measured. Therefore, our aim was to objectively measure the EE of the IT and CT programmes described in the protocol of the SAINTEX-CAD study (based on Wisloff et al.; ITw and CTw), and the actually performed training intensities in the SAINTEX-CAD study by Conraads et al. (ITc and CTc).

**Methods:** Following a two-week run-in period with three IT and three CT training sessions, 18 male CAD patients (mean age $62.4 \pm 6.1$ years) performed four training sessions in random order on the cycle ergometer: an ITw, CTw, ITc and CTc test session. The EE was assessed by indirect calorimetry using gas exchange measurements obtained with the Oxycon mobile.

**Results:** We found a higher EE for CTc compared to ITc ($352 \pm 90.8$ kcal versus $269 \pm 70.7$ kcal; $p = 0.026$), while CTw and ITw seemed to be isocaloric ($317 \pm 85.2$ kcal versus $273 \pm 65.3$ kcal; $p = 0.42$). Higher lactate levels were reached after IT sessions (ITw $5.42 \pm 1.42$ mmol/l, ITc $5.05 \pm 1.38$ mmol/l) compared to CT sessions (CTw $2.45 \pm 1.04$ mmol/l, CTc $3.41 \pm 1.44$ mmol/l) ($p < 0.01$). Lactate levels increased above baseline levels ($1.91 \pm 0.34$ mmol/l) except for the CTw session.

**Conclusion:** CTc expended significantly more energy compared to ITc, showing that the programmes used in the SAINTEX-CAD study were not isocaloric. In contrast, isocaloricity was met for CTw and ITw.

**Keywords**
Isocaloric, energy expenditure, indirect calorimetry, Oxycon mobile, interval training, aerobic exercise, coronary artery disease

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## Introduction

Coronary artery disease (CAD) causes about 45% of all deaths in Europe.[1] Exercise-based cardiac rehabilitation is an effective intervention in the prevention and management of CAD.[2] Substantial evidence shows increases in maximal exercise capacity (peak oxygen uptake ($VO_2$)) after cardiac rehabilitation,[3] with associated decreases in cardiac morbidity and mortality.[4] Therefore, the main aim of exercise-based cardiac rehabilitation is to improve peak $VO_2$. Its effectiveness, however, depends on the intensity, duration, frequency and type of exercise.[2] The search for an optimal training programme is still ongoing and results of comparative studies remain controversial.[5]

The most common training programmes currently used in cardiac rehabilitation are continuous training (CT) and interval training (IT) or a mixture. CT is

[1]Department of Rehabilitation Sciences, KU Leuven, Belgium
[2]Department of Cardiovascular Diseases, University Hospitals of Leuven, Belgium

**Corresponding author:**
Luc Vanhees, Department of Rehabilitation Sciences, Tervuursevest 101, B 1501 B 3001, Leuven, Belgium.
Email: luc.vanhees@kuleuven.be

usually performed at an intensity of 40–80% of the peak $VO_2$.[2] A decade ago, it was shown that IT, consisting of several bouts of exercise at a higher intensity (80–90% of the peak $VO_2$) alternated by active recovery periods, may provide a safe alternative to CT in CAD patients.[6] However, the results from subsequent comparative studies are conflicting and inconsistent with some studies showing that IT and CT equally improve peak $VO_2$,[7–10] while others suggest that IT is superior to CT.[6,11–14] One of the possible reasons for these inconsistencies in literature might be that the training protocols not only differ in intensity, but also in energy expenditure (EE). Indeed, at the population level significant correlations are found between peak $VO_2$ and physical activity EE and also between changes in these variables.[15] Furthermore, Church et al. demonstrated a graded dose-response change in physical fitness with increasing EE of the exercise training programmes at a constant exercise intensity.[16] In line with this, Vanhees et al. showed that exercise intensity and frequency are independent determinants of the change in peak $VO_2$.[17] Given that the duration of the training sessions was similar, a higher exercise frequency will result in a higher exercise EE, leading to higher increases in peak $VO_2$.[17]

Three recent meta-analyses documented that IT results in a significantly larger effect on peak $VO_2$ when compared to CT in CAD patients.[18–20] The effect of IT on peak $VO_2$ was shown to be almost twice the amount of the effect of CT (20.5% vs 12.8%).[19] Of the nine studies included in the meta-analysis of Pattyn et al.,[19] seven reported to compare isocaloric training programmes[6,8,11,21–24] and two did not mention EE.[7,9] For example, in the first comparative IT versus CT study in CAD patients, Rognmo et al. compared training programmes with the same total training workload calculated by the total $VO_2$-time relationship. The calculated average peak $VO_2$ of all subjects during the two exercise intensities of the IT protocol ($3 \times 3$ min at 60% of peak $VO_2$ and $4 \times 4$ min at 90% of peak $VO_2$) was used to derive the duration of the CT protocol (60% of peak $VO_2$) required to yield the same workload.[6] Later studies referred to this method for designing isocaloric training programmes.[11,22,25] Two other methods for calculating training workload, based on heart rate (HR), include Banister's training impulse method (the TRIMP method), used by Iellamo et al.,[23] and Edwards' HR-based method.[26]

To the best of our knowledge, however, no study objectively measured the actual EE of IT and CT. Moreover, some studies did not describe or refer to the formulae used to document the isocaloricity of their training programmes.[8,24]

The purpose of our study is therefore to objectively measure the actual EE of the IT and CT programmes as described in the protocol of the SAINTEX-CAD study (based on Wisloff et al.),[22] and the actually performed training intensities of the SAINTEX-CAD study.[10]

## Methods

### Participants

Our study included 20 male CAD patients (mean age $62.4 \pm 6.1$), referred to the Cardiac Rehabilitation Unit from the University Hospitals of Leuven between July 2014–November 2015. Subjects signed a written informed consent prior to participation in accordance with the Declaration of Helsinki.[27] The study was approved by the local ethics committee (Commissie Medische Ethiek KU Leuven).

The inclusion criteria were: (a) patients with CAD without heart failure, acute myocardial infarction (AMI), percutaneous coronary intervention (PCI) and/or coronary artery bypass grafting (CABG); (b) left ventricular ejection fraction (LVEF) higher than 40%; (c) under optimal medical care; (d) stable with regard to symptoms and pharmacotherapy for at least four weeks; and (e) having completed at least three conventional cardiac rehabilitation training sessions, with a maximum of 15.

A flowchart of the trial is shown in Figure 1. After inclusion, two patients dropped out before any tests were performed: one patient because of an old knee injury and one due to severe arrhythmias at high training intensities. There were no significant differences between the baseline characteristics of the patients with or without the dropouts (data not shown).

### Measurements

*Anthropometric measurements.* Height (cm) and weight (kg) were measured, and body mass index (BMI) ($kg/m^2$) was calculated by dividing weight (kg) by height squared ($m^2$).

*Cardiopulmonary exercise test.* Before starting the cardiac rehabilitation, subjects performed a maximal graded exercise test on a cycle ergometer (Oxycon Pro, Jaeger, CareFusion, Germany) supervised by a trained exercise physiologist. A protocol of 20 watts (W) + 20 W/min until exhaustion was used. During the test, breath-by-breath gas exchange measurements were monitored continuously, allowing online determination of ventilation (VE), oxygen uptake ($VO_2$), and carbon dioxide production ($VCO_2$). In addition, a 12-lead electrocardiogram was continuously registered. The peak HR was defined as the highest HR reached at the end of the test. The peak $VO_2$ was determined as the

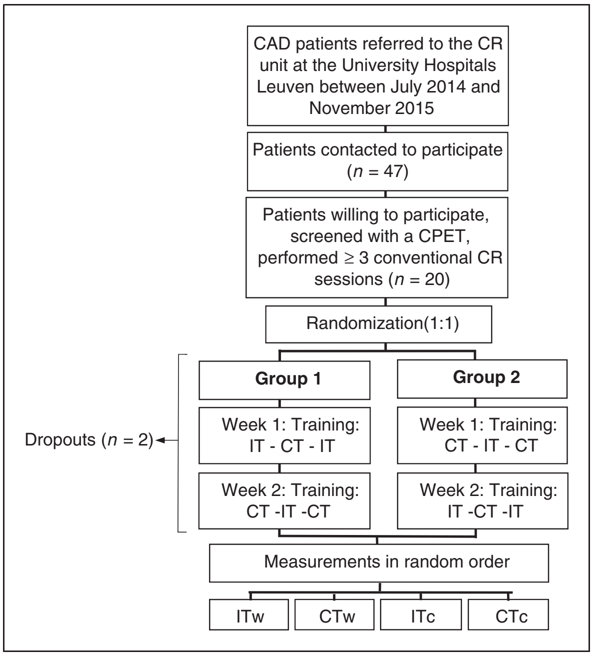


**Figure 1.** Flowchart of the trial. CAD: coronary artery disease; CPET: cardiopulmonary exercise test; CR: cardiac rehabilitation; CT: continuous training; CTc: continuous training according to the SAINTEX-CAD study of Conraads et al.;[10] CTw: continuous training according to the study of Wisloff et al.;[22] IT: interval training; ITc: interval training according to the SAINTEX-CAD study of Conraads et al.;[10] ITw: interval training according to the study of Wisloff et al.[22]

$VO_2$ during the last full bout of 30 s of the test. A peak respiratory exchange ratio of at least 1.10 defined a maximal effort.[28] Individual peak $VO_2$ results were compared with predicted reference values of Wasserman et al. to determine percentage of predicted peak $VO_2$.[29] The first ventilatory threshold was defined as 'the nadir or first increase of ventilation (VE) over oxygen uptake ($O_2$) ($VE/VO_2$) versus workload without a simultaneous increase in VE over carbon dioxide production ($VCO_2$) ($VE/VCO_2$) versus workload' (p 730, Table 2).[30] The second ventilatory threshold was defined as 'the nadir or non-linear increase of $VE/VCO_2$ versus workload'.[30]

## IT and CT familiarisation sessions

After inclusion, subjects were randomly assigned on a 1:1 base to either training group 1 (starting with IT) or group 2 (starting with CT). They performed a total of six supervised IT ($n=3$) and CT ($n=3$) sessions on a cycle ergometer (Ergo-fit, Gymna, Brussels, Belgium), three times per week for two weeks. The IT and CT sessions were alternated and aimed to familiarise the subjects with both training programmes. A Garmin chest strap and wristwatch continuously monitored HR (Garmin, Garmin International, Kansas, USA), and training loads were adapted throughout the training to ensure that participants would remain within the prescribed HR zones.

## IT and CT test sessions

The two-week run-in period was followed by four test sessions within two weeks: the IT and CT according to the protocol of the SAINTEX-CAD study,[25] which was based on Wisloff et al. (ITw and CTw),[22] and the IT and CT according to the actually achieved intensities in the SAINTEX-CAD study of Conraads et al. (ITc and CTc).[10] An online randomisation procedure was performed to determine the sequence of the four test sessions. A visual representation of the IT and CT programmes including their specific training intensities and durations is shown in Figure 2.

During the test sessions, HR was continuously monitored using a Polar chest strap (Polar, Polar Electro, Kempele, Finland). Training loads were adapted throughout the test to ensure that participants would remain within the prescribed HR zones. Each patient performed all four test sessions at the same time in the morning (0800, 0930 or 1100). As beta-blocking medication might influence HR, we also asked our patients to take their medication at the same time each morning of the test.

Breath by breath gas exchange measurements (VE, $VO_2$, $VCO_2$), averaged each 30 s, were provided by the Oxycon mobile device (Oxycon mobile Jaeger, CareFusion, Germany) and were used to calculate the EE (indirect calorimetry) according to the American College of Sports Medicine (ACSM) guidelines; one litre of $O_2$ uptake equals 5 kcal.[5,31]

Lactate levels were determined at baseline; at the end of each four-minute interval for the IT sessions; and at 10, 20, 30 and 37 min of the continuous bout for the CT session, using the Lactate Pro 2 device (Lactate Pro 2, Arkray, Shiga, Japan).

## Statistical analysis

All values are expressed as mean ± standard deviation (SD), median and range, or as number and percentage. Statistical analyses were performed in SAS 9.3 (SAS Institute, Cary, North Carolina, USA). All data were normally distributed according to the Shapiro-Wilk test for normality. To examine the differences in EE, exercise intensity or lactate between the ITw, CTw, ITc and CTc session, a repeated measures analysis of variance (ANOVA) was performed. The Scheffé test for multiple comparisons was used as a post-hoc test. A $p$-value $< 0.05$ was considered statistically significant.

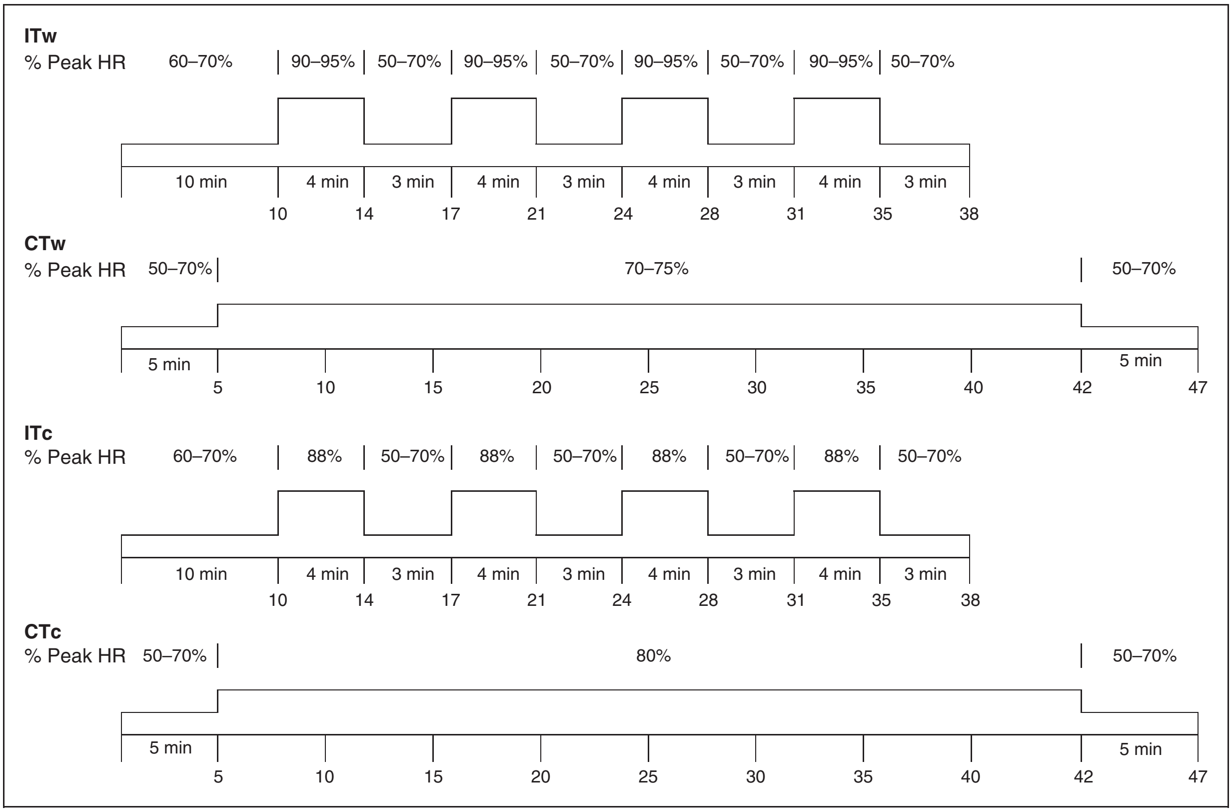


**Figure 2.** A visual presentation of the interval training (IT) and continuous training (CT) exercise programmes. CTc: continuous training according to the SAINTEX-CAD study of Conraads et al.;[10] CTw: continuous training according to the study of Wisloff et al.;[22] ITc: interval training according to the SAINTEX-CAD study of Conraads et al.;[10] ITw: interval training according to the study of Wisloff et al.;[22] % peak HR: percentage of peak heart rate.

As this is the first study to evaluate EE of different exercise programmes, without precedence on which to base accurate power calculations, a sample size calculation could not been performed. However, at completion of the study, we performed a post-hoc power calculation. For a repeated measures ANOVA (within factors) with an $\alpha$ probability of 0.05, a total sample size of 18 and a calculated effect size of 0.45 we had a power of 99.6% to detect significant differences in EE between the four exercise sessions.

HR (bpm) and $VO_2$ (ml/min) were averaged every 30 s during the tests. To calculate the EE with the ACSM formula, data of the total session measured per 30 s (IT 38 min; CT 47 min) were used. In order to document the training intensities, HR and $VO_2$ measurements were averaged for the total four-minute high intensity bouts ($4 \times 4$ min), the total three-minute recovery bouts ($4 \times 3$ min) and the total continuous bout (37 min) (total HR and $VO_2$), and expressed as a percentage of the peak HR and $VO_2$. In addition, the HR and $VO_2$ values of the last minute of each four-minute interval and the last minute of each three-minute recovery bout for IT, and at 10', 20', 30' and 37' for CT were averaged, after which an additional average was calculated of these four measurements (end HR and $VO_2$). These values were also expressed as a percentage of the peak HR and $VO_2$.

## Results

A total of 18 patients completed the six training sessions and the four tests; baseline characteristics are presented in Table 1. Patients did not change medication during the study period.

Figure 3 shows a consistent pattern for total EE in all participants, with CTc expending the largest amount of energy, followed by CTw (except in participant 1 and 10) and then ITw and ITc. In Figure 4 and Table 2, the mean EE per training session is presented. We found that CTw and ITw were isocaloric ($p = 0.42$), while CTc expended significantly more energy compared to ITc ($p = 0.026$) (Table 2). Moreover, CTc resulted in a higher EE compared to ITw ($p = 0.037$).

**Table 1.** Baseline characteristics of the participants.

| Variables | Participants ($n = 18$) |
|---|---|
| *Characteristics and resting variables* | |
| Age (years) | 62.4 ± 6.1 |
| Height (cm) | 173 ± 7.8 |
| Weight (kg) | 86.5 ± 15.1 |
| BMI (kg/m$^2$) | 28.9 ± 3.9 |
| Resting HR (bpm) | 67.1 ± 15.4 |
| Resting SBP (mmHg) | 121 ± 16.0 |
| Resting DBP (mmHg) | 70.9 ± 9.9 |
| LVEF (%) | 57.1 ± 6.1 |
| Training sessions before starting (median and range) | 8 (3–14) |
| *Exercise variables* | |
| Peak $VO_2$ (ml/kg/min) | 23.2 ± 7.0 |
| % $VO_2$ predicted | 91.4 ± 24.2 |
| Peak HR (bpm) | 137 ± 15.2 |
| Peak RER | 1.22 ± 0.10 |
| $VO_2$ at first threshold (ml/kg/min) | 12.7 ± 4.2 |
| % of peak $VO_2$ at first threshold | 55.8 ± 6.5 |
| HR at first threshold (bpm) | 93.1 ± 9.6 |
| % of peak HR at first threshold | 68.1 ± 7.1 |
| $VO_2$ at second threshold (ml/kg/min) | 19.6 ± 6.1 |
| % of peak $VO_2$ at second threshold | 86.4 ± 9.4 |
| HR at second threshold (bpm) | 122 ± 14.2 |
| % of peak HR at second threshold | 88.6 ± 7.1 |
| *Reason for referral to CR* | |
| CABG | 8 (44%) |
| AMI + PCI | 6 (33%) |
| PCI | 4 (22%) |
| *Cardiovascular risk factors* | |
| Familial predisposition | 10 (56%) |
| Hypertension | 11 (61%) |
| Diabetes | 4 (22%) |
| Hyperlipidaemia | 13 (72%) |
| Obesity | 9 (50%) |
| Current smoker | 1 (6%) |
| *Medication* | |
| ASA | 18 (100%) |
| Thienopyridines | 11 (61%) |
| Beta-blockers | 16 (89%) |
| ACE-inhibitors | 10 (56%) |
| ARB | 2 (11%) |
| Statins | 17 (94%) |
| Calcium antagonists | 2 (11%) |
| Diuretics | 1 (6%) |
| Anti-diabetic medication | 4 (22%) |

ACE: angiotensin-converting enzyme; AMI: acute myocardial infarction; ARB: angiotensin II receptor blocker; ASA: acetylsalicylic acid; BMI: body mass index; CABG: coronary artery bypass grafting; CR: cardiac rehabilitation; DBP: diastolic blood pressure; HR: heart rate; LVEF: left ventricular ejection fraction; PCI: percutaneous coronary intervention; RER: respiratory exchange ratio; SBP: systolic blood pressure; $VO_2$: oxygen uptake.
Data are presented as means ± standard deviation (SD), median and range, or number and percentage. Familial predisposition: first or second degree relative with cardiovascular problems before age 50 (men) or 55 (women) years; hypertension: blood pressure >140/90 mm Hg or taking anti-hypertensive medication; diabetes: glycated haemoglobin >6.5% or taking anti-diabetic medication; hyperlipidaemia: total cholesterol >190 mg/dl, triglycerides >150 mg/dl, low-density lipoprotein cholesterol (LDL-C) >115 mg/dl or taking statins; obesity: body mass index >30 kg/m$^2$;

Mean baseline lactate was 1.91 ± 0.34 mmol/l. Lactate levels for ITw ($p < 0.001$), ITc ($p < 0.001$) and CTc ($p = 0.009$) increased significantly compared to baseline, while lactate levels during CTw did not change ($p = 0.86$). The lactate levels for the IT programmes were significantly higher compared to those of the CT sessions ($p < 0.01$) (Table 2).

The patients performed the tests within the prescribed HR zones (taking into account the end-interval values for the IT sessions) as shown in Table 2 and in Figure 5.

## Discussion

This is the first study to objectively measure EE during IT and CT. In order to conclude adequately whether IT or CT is superior, protocols have to be comparable. Therefore in previous studies, training sessions were designed to be isocaloric based on a theoretical calculation of their respective EE. Results of these comparative studies were inconsistent. The present study examines whether the IT and CT programmes described in the protocol of the SAINTEX-CAD study[25] (based on a study of Wisloff et al.: ITw and CTw),[22] and the actually achieved intensities in the SAINTEX-CAD study (ITc and CTc),[10] were truly isocaloric by objectively measuring the EE.

Our results showed: (a) a similar EE for the protocols of Wisloff et al. (ITw vs CTw); (b) a significantly higher EE for the CT of the SAINTEX-CAD study compared to the IT (ITc vs CTc); (c) a significant increase in lactate after ITw, ITc and CTc, but not

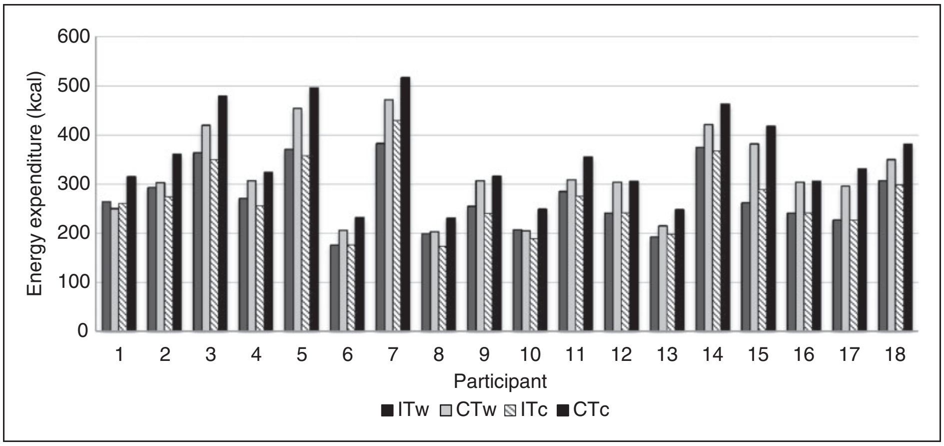


**Figure 3.** Energy expenditure per participant for each test. CTc: continuous training according to the SAINTEX-CAD study of Conraads et al.;[10] CTw: continuous training according to the study of Wisloff et al.;[22] ITc: interval training according to the SAINTEX-CAD study of Conraads et al.;[10] ITw: interval training according to the study of Wisloff et al.[22]

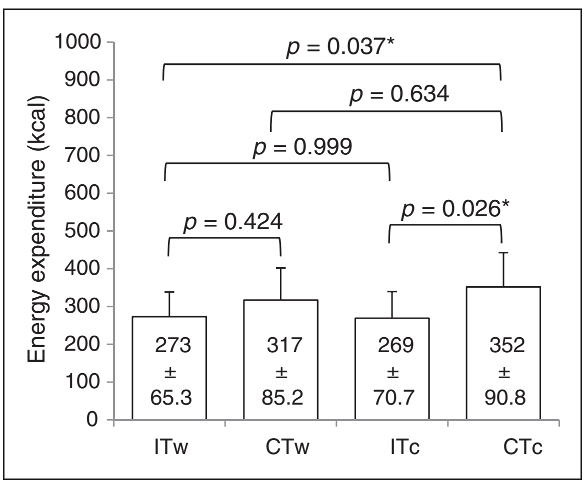


**Figure 4.** Comparison of the energy expenditures according to the study of Wisloff et al.[22] and according to the SAINTEX-CAD study of Conraads et al.[10] Other not-mentioned comparisons were not significantly different. CTc: continuous training according to the SAINTEX-CAD study of Conraads et al.;[10] CTw: continuous training according to the study of Wisloff et al.;[22] ITc: interval training according to the SAINTEX-CAD study of Conraads et al.;[10] ITw: interval training according to the study of Wisloff et al.;[22] * $p < 0.05$.

after CTw, compared to resting lactate levels; and (d) significantly higher lactate levels after IT sessions compared to CT sessions.

Rognmo et al.[6] used similar IT and CT protocols as Wisloff et al.[22] in CAD patients and found that IT was superior to CT in improving peak $VO_2$ (+17.9% versus + 7.9%); Conraads et al. reported that both protocols were equally effective in improving peak $VO_2$ (+22.7% versus + 20.3%).[10] However, Conraads et al. came to the conclusion that a number of CAD patients were incapable of maintaining 90–95% of their peak HR throughout the four-minute interval, and they moreover observed that the intensity of CT in the prescribed protocol (70–75% of peak HR)[6,22] was probably insufficient to achieve usual improvements[3] in peak $VO_2$. These different training intensities (ITc lower and CTc higher than prescribed) may explain the differences in results and conclusions between these studies.[10] In addition, Conraads et al. consequently advised that CT should be set at an intensity higher than 70–75% of peak HR, which can still be sustained for 37 min.[10]

In the current study, all subjects (except two) were able to perform the ITw test within the predefined HR zones, with an average of 91.2 ± 3.7% peak HR at the end of the high intensity interval. Nevertheless, most of the patients had difficulties maintaining this high HR zone and needed constant encouragement from the supervising exercise physiologist. The intensity set at 93% of peak HR was above the second ventilatory threshold (88.6% of peak HR, Table 1), which makes this effort very difficult to sustain. During the ITc session, intensity was set at 88% of peak HR, just below the second ventilatory threshold, which was clearly easier to tolerate. Despite the differences in training HR, EE during ITw and ITc seemed to be similar (ITw 273 kcal vs ITc 269 kcal). Nevertheless, Moholdt et al. showed that even within the high intensity training zones, exercise intensity was an important determinant for improving peak $VO_2$, with categories < 88% and > 92% of peak HR resulting in significantly different increases.[32] Based on this information, it seems that training intensity is a more important determinant for achieving favourable training responses compared to EE (training volume = duration × intensity),

**Table 2.** Energy expenditure, lactate levels and training characteristics for each test.

| Variable | ITw | CTw | ITc | CTc | *p*-Value | Post-hoc Scheffé results |
|---|---|---|---|---|---|---|
| Energy expenditure (kcal) | $273 \pm 65.3$ | $317 \pm 85.2$ | $269 \pm 70.7$ | $352 \pm 90.8$ | $p = 0.006$ | ITw < CTc; ITc < CTc |
| Mean lactate (mmol/l) | $5.42 \pm 1.42$ | $2.45 \pm 1.04$ | $5.05 \pm 1.38$ | $3.41 \pm 1.44$ | $p < 0.001$ | ITw > CTw; ITc > CTc; ITw > CTc; ITc > CTw |
| *Training intensity* | | | | | | |
| % Peak HR prescribed (interval) | 90–95 | 70–75 | 88 | 80 | | |
| % Peak HR end interval | $91.2 \pm 3.7$ | $73.6 \pm 1.1$ | $87.1 \pm 1.9$ | $79.7 \pm 1.6$ | $p < 0.001$ | ITw > CTw; ITc > CTc; ITw > CTc; ITc > CTw; ITw > ITc; CTw > CTc |
| % Peak HR total interval | $86.0 \pm 3.7$ | $73.1 \pm 0.9$ | $82.7 \pm 2.6$ | $78.3 \pm 1.9$ | $p < 0.001$ | ITw > CTw; ITc > CTc; ITw > CTc; ITc > CTw; ITw > ITc; CTw > CTc |
| % Peak HR prescribed (recovery) | 50–70 | 50–70 | 50–70 | 50–70 | | |
| % Peak HR end recovery | $71.1 \pm 5.2$ | $65.2 \pm 4.5$ | $68.6 \pm 4.3$ | $69.2 \pm 4.5$ | $p = 0.003$ | ITw > CTw |
| % Peak HR total recovery | $75.7 \pm 4.9$ | $66.9 \pm 3.9$ | $72.9 \pm 3.5$ | $71.2 \pm 3.9$ | $p < 0.001$ | ITw > CTw; ITw > CTc; ITc > CTw; CTc > CTw |
| % Peak $VO_2$ end interval | $104 \pm 13.4$ | $75.5 \pm 10.9$ | $100 \pm 11.5$ | $85.2 \pm 11.9$ | $p < 0.001$ | ITw > CTw; ITc > CTc; ITw > CTc; ITc > CTw |
| % Peak $VO_2$ total interval | $92.2 \pm 11.0$ | $74.6 \pm 10.7$ | $89.9 \pm 10.0$ | $83.6 \pm 10.9$ | $p < 0.001$ | ITw > CTw; ITc > CTw |
| % Peak $VO_2$ end recovery | $58.9 \pm 8.8$ | $55.1 \pm 9.8$ | $58.4 \pm 7.4$ | $55.3 \pm 8.4$ | $p = 0.40$ | |
| % Peak $VO_2$ total recovery | $71.9 \pm 10.3$ | $60.0 \pm 9.6$ | $70.4 \pm 8.4$ | $60.7 \pm 8.1$ | $p < 0.001$ | ITw > CTw; ITc > CTc; ITw > CTc; ITc > CTw |

CTc: continuous training according to the SAINTEX-CAD study of Conraads et al.;[10] CTw: continuous training according to the study of Wisloff et al.;[22] HR: heart rate; ITc: interval training according to the SAINTEX-CAD study of Conraads et al.;[10] ITw: interval training according to the study of Wisloff et al.;[22] $VO_2$: oxygen uptake.

as both IT sessions seem to be similar in volume and duration.

Whereas also the CT sessions seemed to be similar in EE (CTw 317 kcal vs CTc 352 kcal), an 11% difference (35 kcal) per session was found. As the durations were similar, the small but not significant differences in intensity might explain the larger gain in peak $VO_2$ in the CT group of the SAINTEX-CAD study ($\pm$20.3%)[10] compared to the study of Rognmo et al. ($\pm$7.9%).[6]

Combining the previous results of the SAINTEX-CAD study (IT and CT equally improved peak $VO_2$) with the present findings, we can conclude that IT is more efficient than CT because of a significantly lower energy cost and training duration for an equal improvement in peak $VO_2$. This is in line with meta-analyses[18–20] aggregating results of IT and CT on peak $VO_2$ in CAD patients, revealing a superior effect following IT. However, isocaloricity and EE of training sessions is not a goal on its own. The most important question remains which training modality is the most appropriate to increase peak $VO_2$, and it seems that both IT and CT are equally effective when sufficiently high intensities are achieved in the CT protocol. Patients should be able to choose their preferred training modality in order to increase their intrinsic motivation for a lifelong physically active lifestyle.

On the other hand, EE is important for weight loss. Our findings support the overall results on body weight in the meta-analysis of Pattyn et al. and Liou et al.[19,20] showing that CT is more effective in reducing body weight since more calories are expended compared to IT. Performing 36 sessions (12 weeks, $3 \times$/week) of CT leads to a 3000 kcal (31%) higher expenditure compared to IT, which equals a difference of almost 0.5 kg fat loss. Thus, we can conclude that IT is more efficient in improving peak $VO_2$, while CT at sufficiently high intensities expends more energy leading to larger reductions in body weight.

According to Skinner's three-phase model, training modalities below the first ventilatory threshold (60–70% peak HR) do not exceed a 2 mmol/l lactate level.[30,33] When lactate levels exceed 4 mmol/l, passing the second ventilatory threshold, the exercise is considered anaerobic (>90% peak HR). In our study, average lactate levels during the training sessions were between 2.45 mmol/l (CTw) and 5.42 mmol/l (ITw). Statistical analysis revealed a significant difference

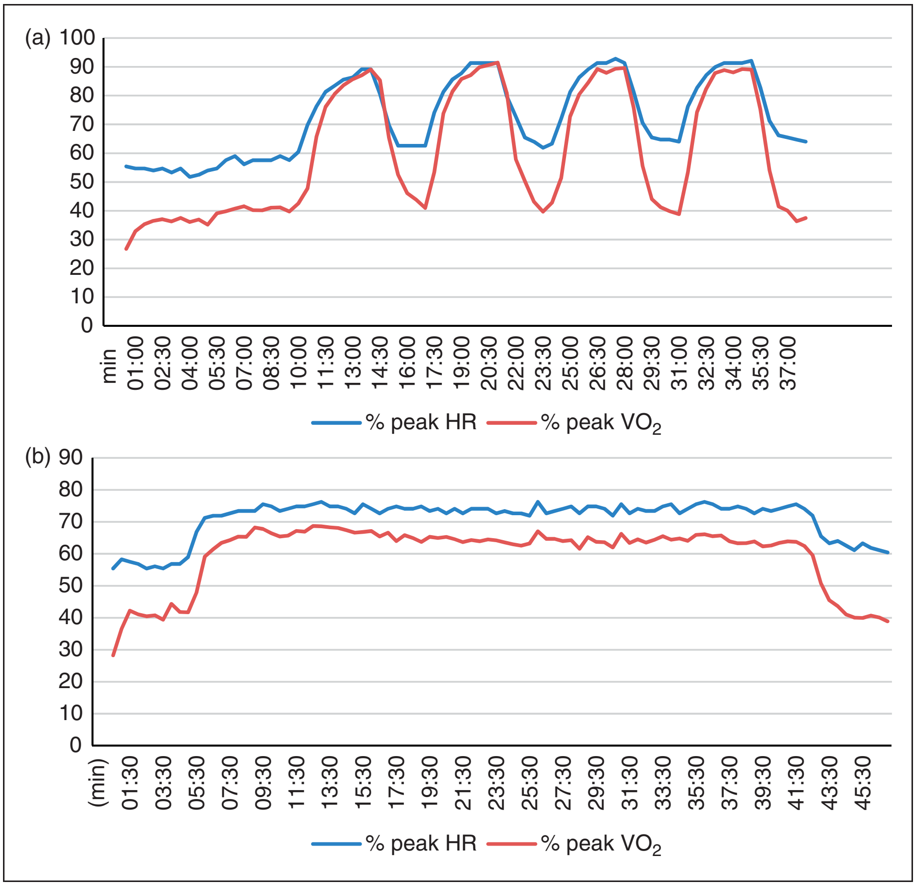


**Figure 5.** Example of the heart rates and oxygen uptakes during (a) initial training and (b) continuous training sessions in a patient under beta-blockade. CTw: continuous training according to the study of Wisloff et al.:[22] HR: heart rate; ITw: interval training according to the study of Wisloff et al.;[22] $VO_2$: oxygen uptake.

between the lactate levels of the CT and IT, with IT showing lactate values > 4 mmol/l. This implies that the high intensity intervals may have been performed anaerobically for most of the individuals (ITw 14/18; ITc 13/18), but not in all, since this secondary threshold is highly individual. The frequently used term 'aerobic' interval training may thus be inappropriate and misleading, but further research is needed. We can however conclude that the participants remained in the aerobic zone for both CT sessions (CTw 2.45 mmol/l and CTc 3.41 mmol/l). From the lactate levels of the CTw session, we can conclude that an intensity set at 70–75% of peak HR is simply insufficient as a training stimulus.

### *Limitations*

The results of this study should be interpreted within the context of its limitations. The first limitation of our study consists of a relatively small sample size. However, our results were highly consistent and the statistical power to detect significant differences in EE between the four sessions was 99.6%.

Second, compared to the Oxycon Pro (a stationary apparatus, used for the maximal exercise test), the Oxycon Mobile (a portable device), which was used for the test sessions, might overestimate $VO_2$ when the intensity exceeds 200 W.[34] Since only one participant went just beyond 200 W during his IT test session, we can consider that our measurements from the Oxycon Mobile were sufficiently accurate.

Third, we determined the HR zones based on one single maximal exercise test. However, many factors can influence this test, which may generate a deviation of the peak HR, resulting in an over or underestimation of the intensity. We expect, however, these variations to be random across all subjects, which should, therefore, not significantly influence our final result.[32] However, this could have led to the fact that two patients were not able to achieve the prescribed intensity during the ITw session.

Fourth, patients already performed at least three conventional training sessions and six familiarisation sessions (>3 weeks) before starting the tests. As we previously reported that substantial changes in peak $VO_2$

and peak HR already occur after six weeks of training,[10] this run-in period could have influenced the high $VO_2$ levels achieved at prescribed HR. For example, patients trained at 100–104% of peak $VO_2$ during IT, and 76–85% of peak $VO_2$ during CT, which is physiologically impossible without a run-in period.

Fifth, we did not measure lactate levels during the maximal exercise test, hence we were unable to compare these individual maximal lactate levels to the lactate levels found during the tests.

## Conclusion

We found that CT according to the SAINTEX-CAD study expended significantly more energy than IT. As previous studies showed IT and CT to either yield similar improvement in peak $VO_2$, or a larger improvements after IT compared to CT, we can conclude that IT is more efficient in improving peak $VO_2$, producing a larger gain during a shorter training duration and at a lower energy cost. However, since EE is not a goal on its own in cardiac rehabilitation, the main question remains which training modality is the most appropriate to increase peak $VO_2$. We can suggest that IT and CT are equally effective, if CT sessions are performed at sufficiently high intensities.

We stress the importance of objectively measuring actual caloric expenditure by indirect calorimetry in pilot studies, rather than using a general formula for setting up isocaloric exercise training programmes.

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